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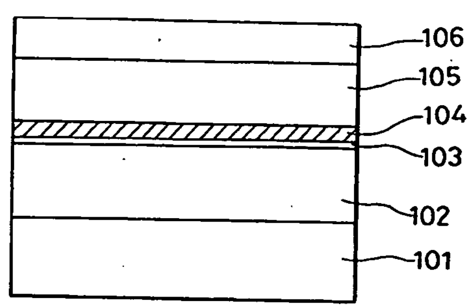
(54) Semiconductor laser device.

(57) A semiconductor laser device includes a first conductivity type cladding layer (102), an active layer (103), and a second conductivity type cladding layer (105), disposed on a first conductivity type substrate (101). A multiquantum barrier (104) comprising superlattice semiconductor layers is disposed between the active layer (103) and either of the cladding layers. The active layer includes a layer having a crystal composition in which a lattice constant of the layer is different from a lattice constant of the first conductivity type substrate by 0.1 percent or more so that a strain may be applied to the layer. Therefore, a threshold current is significantly reduced, resulting in a high power semiconductor laser capable of operating at a high temperature.

F I G. 1

(a)



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the strained active layer.

According to a second aspect of the present invention, a semiconductor laser device includes a multiquantum barrier in which semiconductor layers having large energy band gaps and semiconductor layers having small energy band gaps are alternated with each other, and a strain is applied to at least one of the semiconductor layers. Therefore, a height of a barrier for confining holes is increased.

According to a third aspect of the present invention, a semiconductor laser device includes an active layer to which a strain is applied and a multiquantum barrier disposed between an n type cladding layer and the active layer. The multiquantum barrier is formed by alternating semiconductor layers having large energy band gaps and semiconductor layers having small energy band gaps and a strain is applied to at least one of the semiconductor layers. Therefore, a threshold current is significantly reduced and a height of a barrier for confining holes is increased.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1(a)-1(c) illustrates a schematic diagram showing a semiconductor laser device in accordance with a first embodiment of the present invention;

Figure 2 is a graph showing a relation between a threshold current density and a strain applied to an active layer;

Figures 3(a)-3(b) are cross-sectional views showing a semiconductor laser device in accordance with a second embodiment of the present invention;

Figure 4 is a cross-sectional view showing a semiconductor laser device in accordance with a fourth embodiment of the present invention;

Figures 5(a)-5(b) are cross-sectional views showing a semiconductor laser device in accordance with a fourth embodiment of the present invention;

Figure 6 is a graph showing a relation between a height of a barrier for confining holes varies and an effective mass of the holes;

Figures 7(a)-7(b) are cross-sectional views showing a semiconductor laser device in accordance with a fifth embodiment of the present invention;

Figure 8 is a cross-sectional view showing a semiconductor laser device incorporating an MQB in accordance with the prior art; and

Figure 9 is a schematic diagram of the MQB in accordance with the prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Although the present invention is applicable to all III-V and II-VI compound semiconductor laser devices, a description will be given of an AlGaInP semiconductor laser device producing visible light.

Figure 1(a) is a cross-sectional view showing an AlGaInP laser device producing visible light in accordance with a first embodiment of the present invention. In figure 1(a), reference numeral 101 designates an n type GaAs substrate. An n type $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ cladding layer 102 1.5 microns thick is disposed on the substrate 101 and a $Ga_xIn_{1-x}P$ active layer 103 is disposed on the cladding layer 102. An MQB 104 is disposed on the active layer 103. As shown in figure 1(b), the MQB 104 has a superlattice multilayer structure comprising twenty layers, i.e., a p type $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ buffer layer 104a 226 angstroms thick, ten p type $Ga_{0.5}In_{0.5}P$ well layers 104b each 11.5 angstroms thick, and nine p type $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ barrier layers 104c each 17 angstroms thick. A p type $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ cladding layer 105 1.5 microns thick is disposed on the MQB 104 and a p type GaAs layer 106 0.5 micron thick is disposed on the cladding layer 105. Regarding the crystal composition, $(Al_yGa_{1-y})_xIn_{1-x}$ lattice-matches with GaAs when $x = 0.5$ and $0 < y < 1$. In this embodiment, x is not equal to 0.5 in the $Ga_xIn_{1-x}P$ active layer 103, so that it may not lattice-match with GaAs. More specifically, when $x > 0.5$, since a lattice constant of the $Ga_xIn_{1-x}P$ is smaller than GaAs, a tensile strain is applied to the active layer 103 in the layer structure shown in figure 1(a). When $x < 0.5$, since the lattice constant of the $Ga_xIn_{1-x}P$ is larger than GaAs, a compressive strain is applied to the active layer 103.

In figure 1(c), a height of an effective barrier for confining electrons Ue increases because of the MQB 104. More concretely, the height of the effective barrier Ue is twice as high as a difference in energy band gaps Ec (~150 meV) between the active layer 103 and the p type $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ buffer layer 104a at the conduction band side.

A description is given of laser characteristics of the semiconductor laser device on the basis of a result of an experiment.

When the laser characteristics were examined using a $Ga_xIn_{1-x}P$ active layer 150 angstroms thick while varying x in a range of 0.5 to 0.45, a strain of 0 to 0.45 % was found.

Figure 2 is a graph showing a relation between the strain applied to the active layer 103 and a threshold current density of the laser. As shown in figure 2, when the MQB is provided or the strain is applied to the active layer, the thr shold curr nt density is about 3 KA/cm^2, which means that the

present invention. Figure 5(b) is a cross-sectional view showing a structure of the MQB in detail. In the figures, a strained MQB 304 is inserted between an active layer 103 and an n type cladding layer 102. The MQB 304 comprises twenty layers, i.e., a $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ barrier layer 304a 226 angstroms thick, ten $Ga_zIn_{1-z}P$ well layers 304b each 17 angstroms thick, and nine $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ barrier layers 304c each 11.5 angstroms thick. In addition, the same reference numerals as those in figure 1 designate the same parts.

In the MQB structure of this embodiment, when z is smaller than 0.5 in the $Ga_zIn_{1-z}P$ well layer 304b, a compressive strain is applied to the well layer and an effective mass of holes in the well layer decreases. Figure 6 is a graph logically showing how the height of the barrier for confining holes varies with the decrease in the effective mass of holes. In figure 6, reference character Ev designates an amount of band discontinuity at a va- l nce band at a heterojunction portion between the $Ga_xIn_{1-x}P$ active layer and the $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ cladding layer. Reference character Uh designates the height of the effective barrier for confining holes. Reference character m*ho designates an effective mass of holes in the $Ga_zIn_{1-z}P$ well layer 304b which lattice-matches with GaAs when z is equal to 0.5. Reference character m*h designates an effective mass of holes in the $Ga_zIn_{1-z}P$ well layer 304b when z is smaller than 0.5. In addition, the axis of abscissas shows a ratio of m*h to m*ho and the axis of ordinates shows Uh relative to Ev.

As shown in figure 6, when z is equal to 0.5 in the $Ga_zIn_{1-z}P$, i.e., when m*ho is equal to m*h (m*h/m*ho = 1), Uh is about 1.4 Ev. In other wards, when no strain is applied to the $Ga_zIn_{1-z}P$ well layer 304b, the height of the barrier for confining holes increases by only 40 percent. However, when a compressive strain is applied to the $Ga_zIn_{1-z}P$ well layer 304b, i.e., when z is smaller than 0.5, Uh increases with the decrease in the effective mass of holes. For example, when m*h/m*ho is equal to 0.25, i.e., when the effective mass of holes is reduced, by applying the compressive strain, to one fourth of the effective mass of holes in the case where no strain is applied, Uh is approximately equal to 2.4 Ev, which means that the height of the barrier for confining holes significantly increases.

In this way, the strained MQB of this embodiment is effective in increasing the height of the barrier for confining holes.

In the semiconductor laser device according to this embodiment, the strained MQB 304 is inserted betw en the active layer 103 and the n type cladding layer 102 and the MQB 104, to which no strain is applied, is inserted between the activ layer 103 and the p type cladding layer 105. In this structure, electrons and holes are effectively confined in the active layer by the MQBs 104 and 304 and never overflow into the cladding layers, resulting in a semiconductor laser which oscillates with very low threshold current. In addition, a temperature characteristic of the laser is improved, resulting in a semiconductor laser which operates at a high temperature.

In the fourth embodiment of the present invention, even when the active layer includes no layer to which a strain is applied, since the strained MQB significantly increases the height of the barrier for confining holes, the same effect as described above is obtained.

In addition, since the strained MQB also increases the height of the barrier for confining electrons, the strained MQB may be inserted between the p type cladding layer and the active layer.

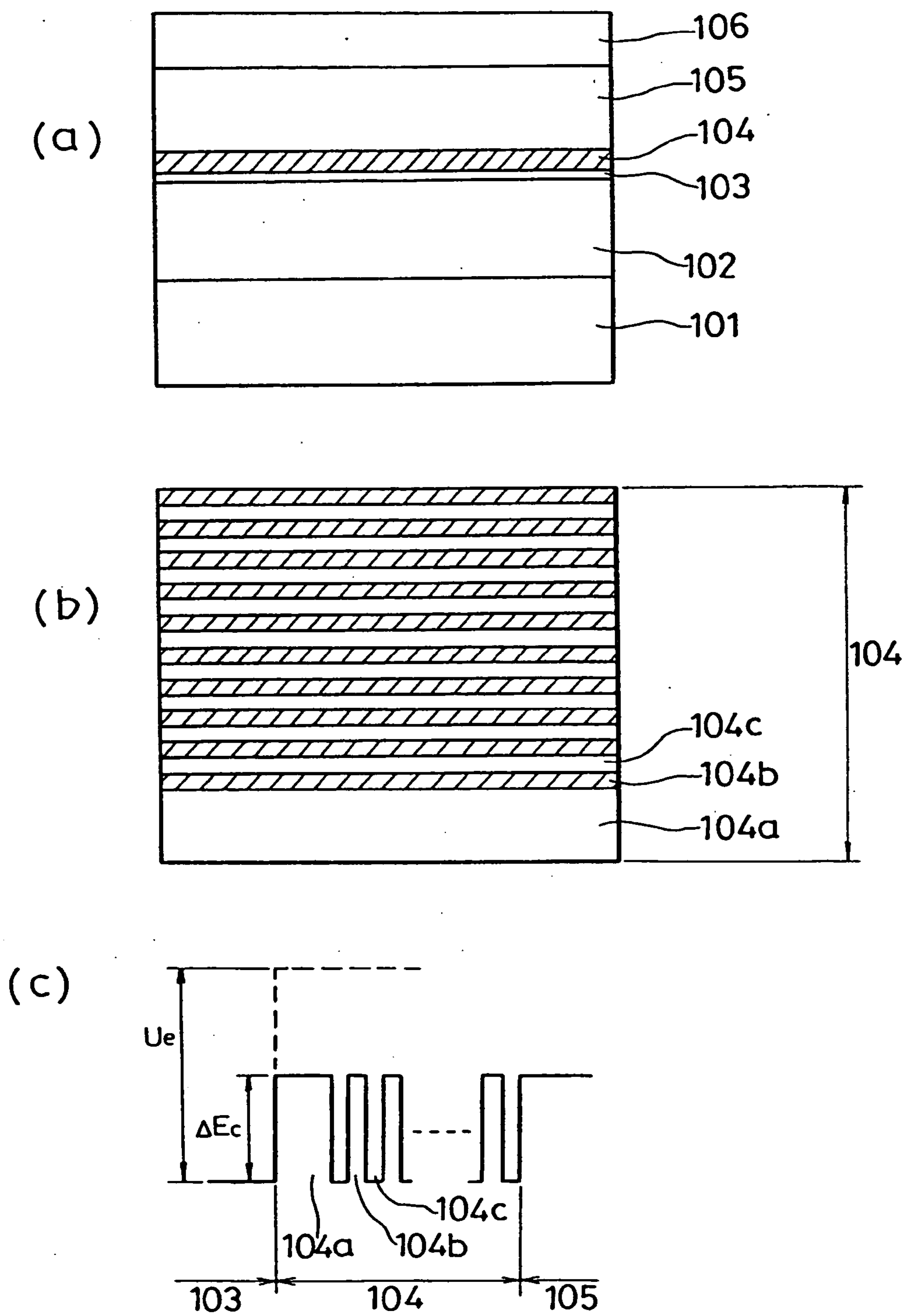
Figure 7(a) is a cross-sectional view showing a semiconductor laser device incorporating an MQB in accordance with a fifth embodiment of the present invention and figure 7(b) is a cross-sectional view showing the MQB in detail.

In this fifth embodiment, a description is given of an MQB which is effective in improving characteristics of an AlGaInP laser device producing visible light.

In figure 7(b), an MQB 404 has a superlattice multilayer structure comprising a plurality of AlGaInP barrier layers 404a and a plurality of AlGaAs well layers 404b. An energy band gap of the barrier layer 404a should always be higher than that of the well layer 404b. For example, when the barrier layer 404a comprises $(Al_{0.7}GA_{0.3})_{0.5}In_{0.5}P$ and the well layer 404b comprises GaAs, a difference in energy band gaps between these layers is about 1.6 eV. This is by 1.2 eV larger than the difference in energy band gaps of 0.4 eV between the $Ga_{0.5}In_{0.5}P$ well layer and the $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ barrier layer shown in figure 1(b). Therefore, the height of the barrier for confining carriers is further increased.

Furthermore, another merit of this embodiment resides in that the well layer 304b can be highly doped. Generally, it is difficult to dope impurities into AlGaInP to a high concentration. Accordingly, the MQB comprising only AlGaInP system material has a relatively high resistance, increasing series resistance of the laser. As the result, consumption power of the laser increases. In the MQB structure of this embodiment, since the well layer comprises AlGaAs system material to which impurities can be doped to a high concentration, the resistance of the MQB its lf is reduced and the series resistance of the laser is reduced. Thus, th height of the effective barrier caused by the MQB is further increased while the seri s r sistance caused by th MQB is reduced, r sulting in a semiconductor laser device

F I G. 1


(a)
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103
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101
(b)
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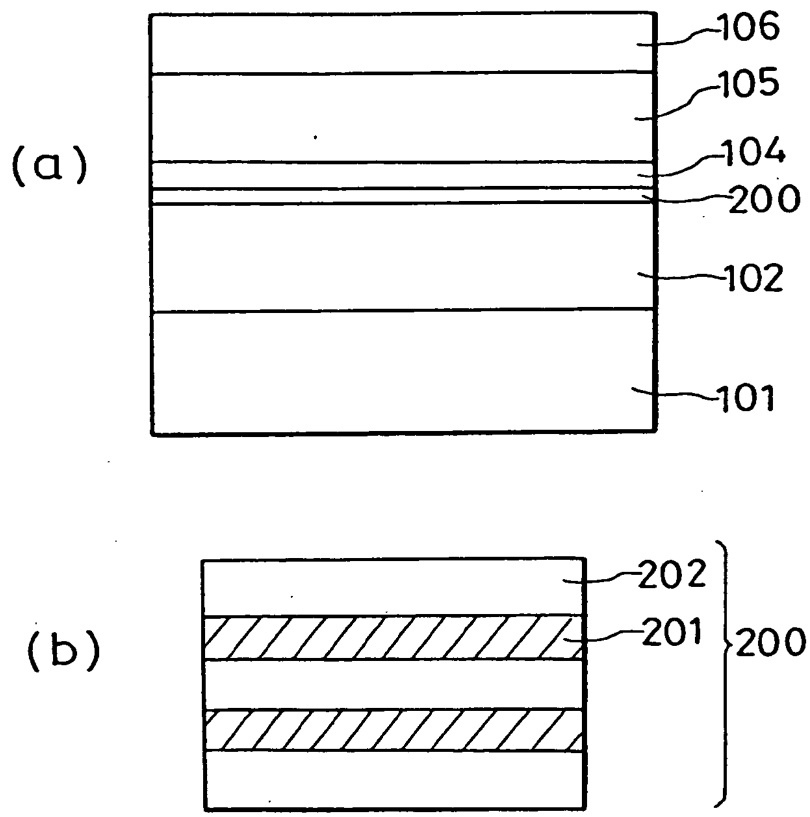
103
104
105

FIG. 3


(a)
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(b)
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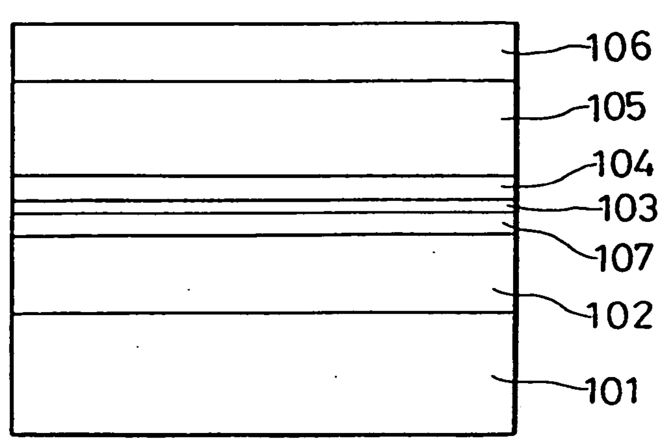
201
200

FIG. 4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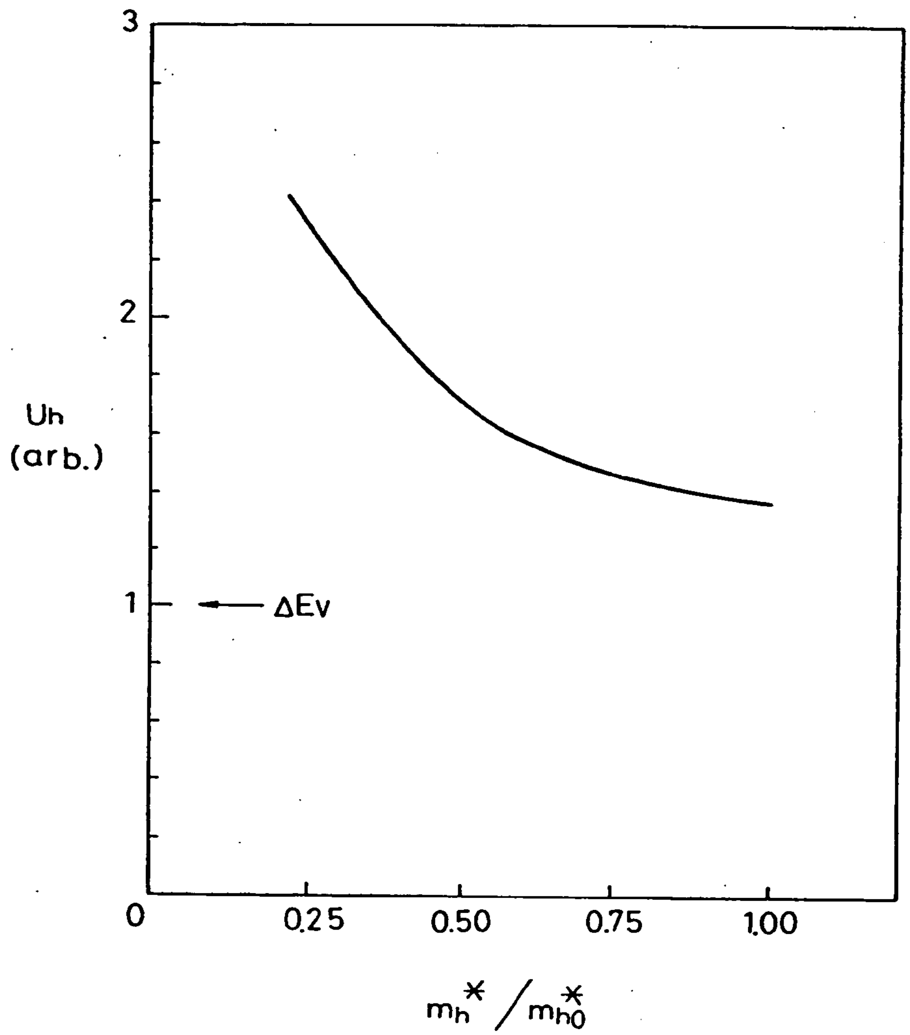
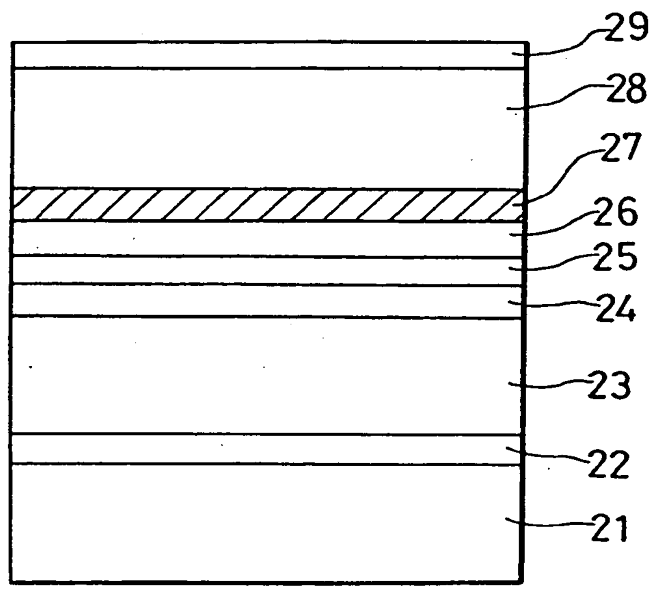
102
101

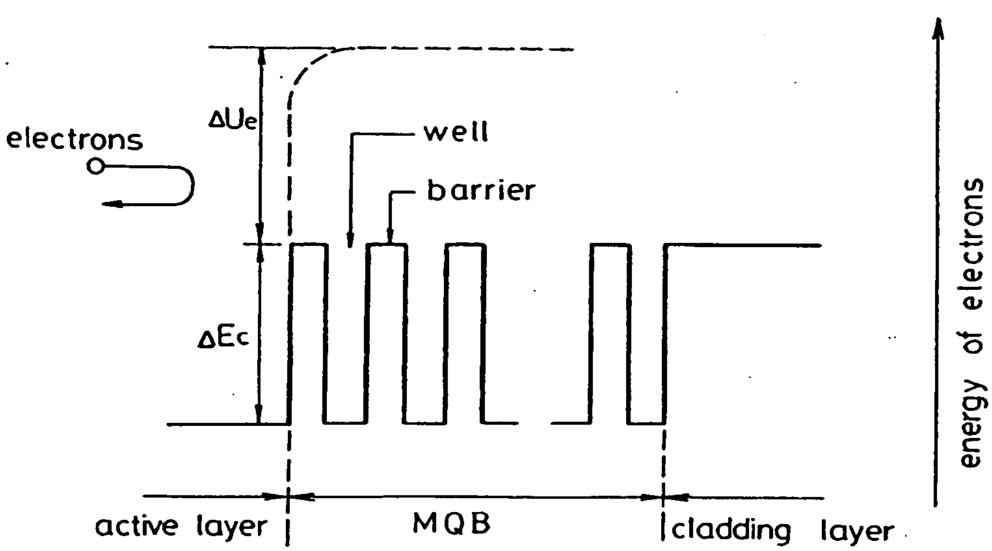
FIG. 6



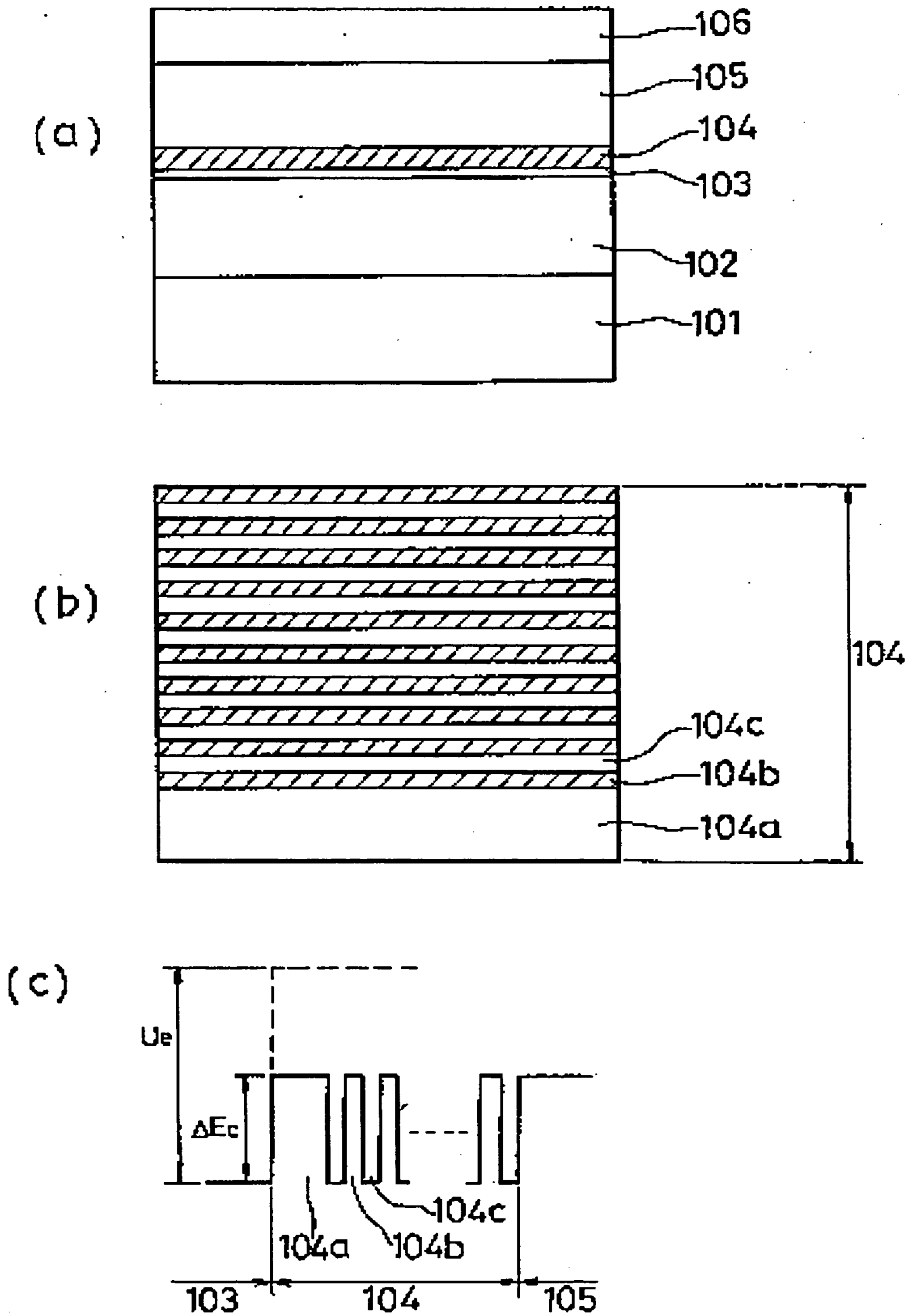
F I G. 8 (PRIOR ART)



F I G. 9 (PRIOR ART)



F I G. 1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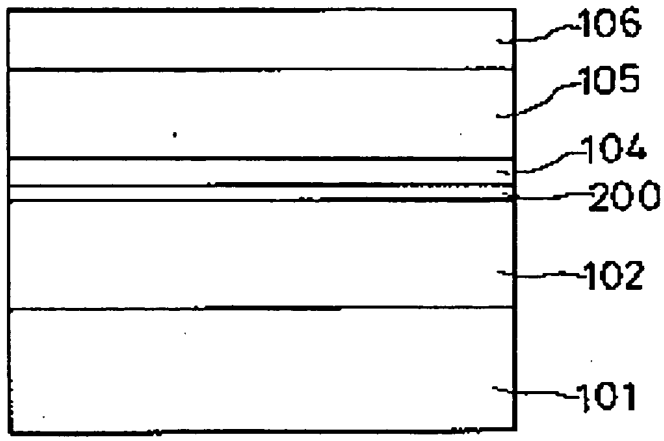
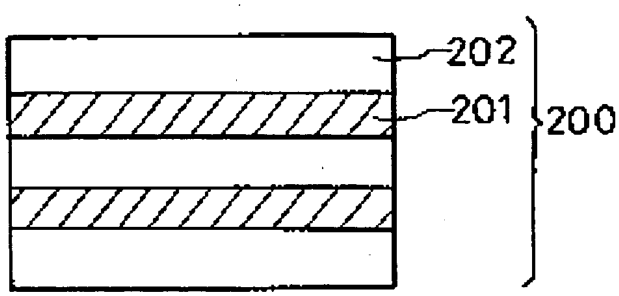
F I G. 3

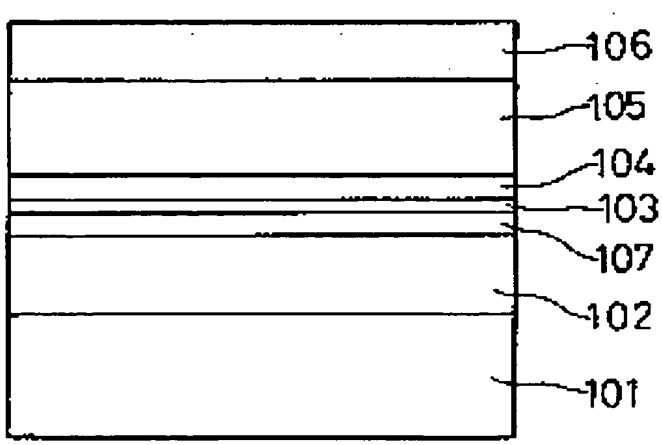
(a)



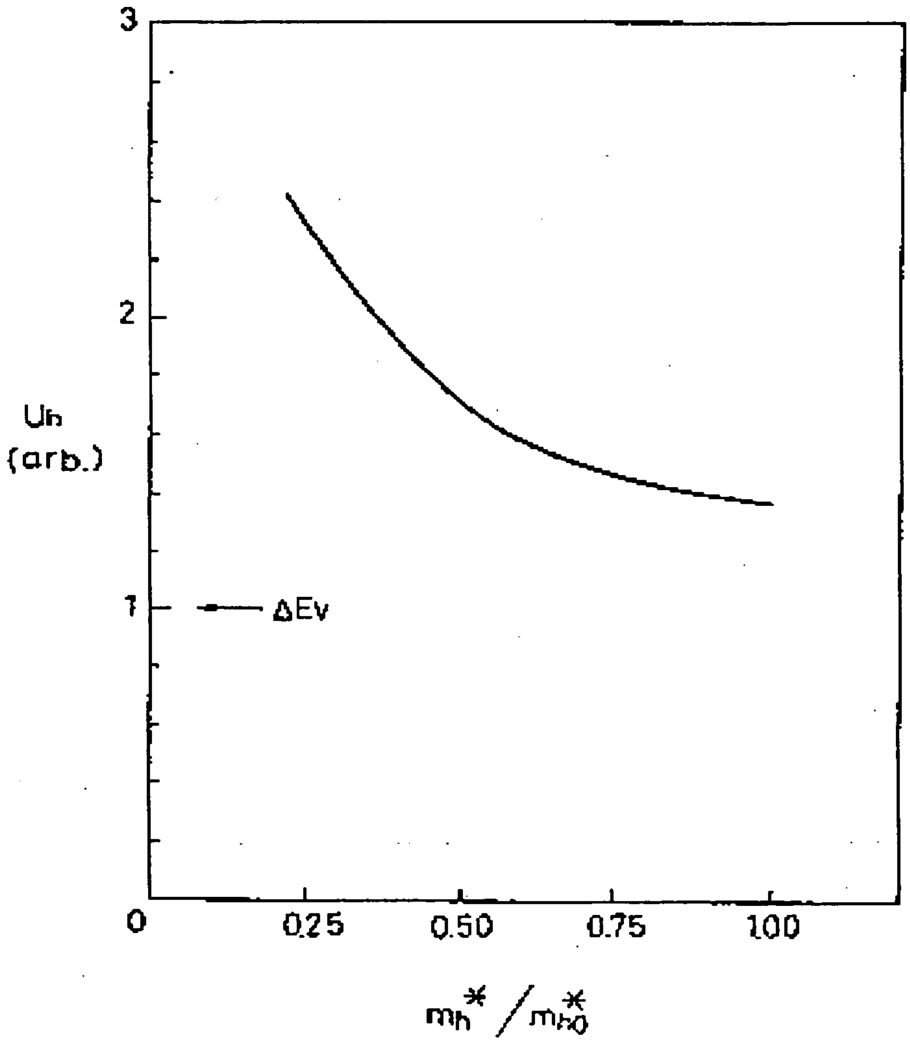
(b)



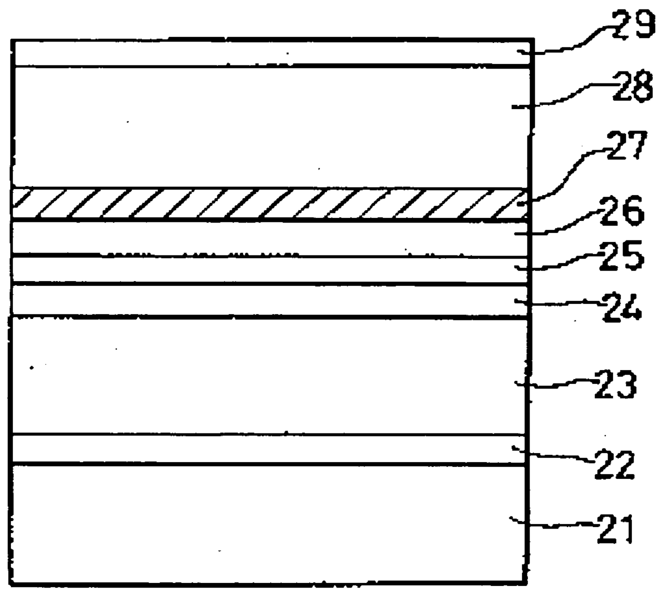
F I G. 4



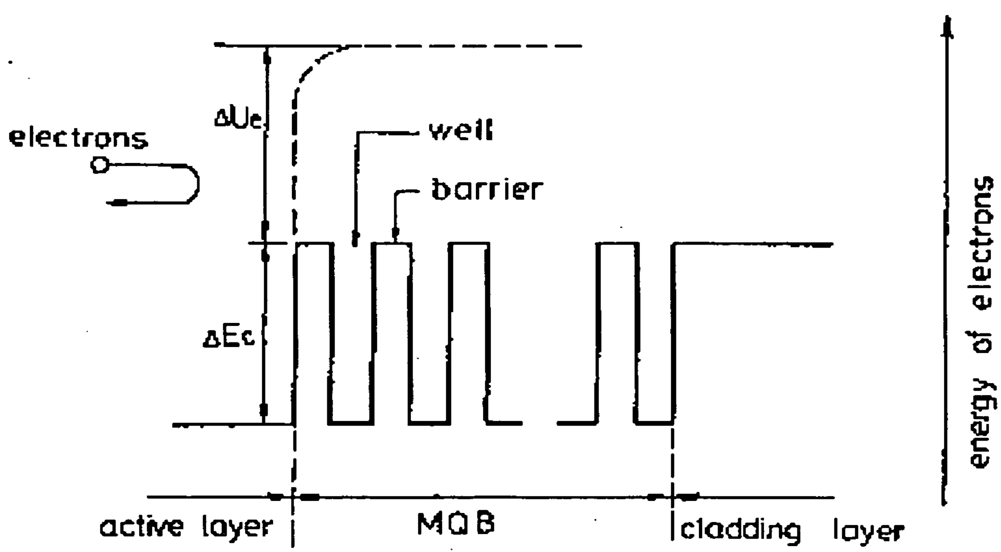
F I G. 6



F I G. 8 (PRIOR ART)



F I G. 9 (PRIOR ART)



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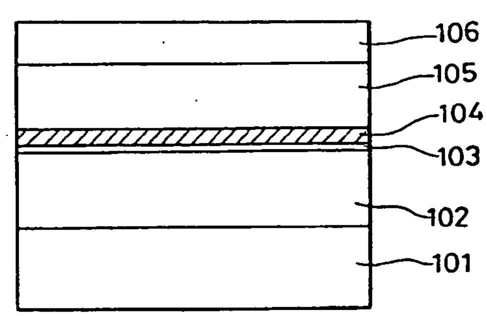
F I G. 1

(a)



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European Patent Office

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

☐ All claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for all claims.

☐ Only part of the claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid,

namely claims:

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions,
namely:

see sheet -B-

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid,

namely claims:

☐ None of the further search fees has been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims,

namely claims: